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AUG 79 P V VERSAGE, A M FERRARA

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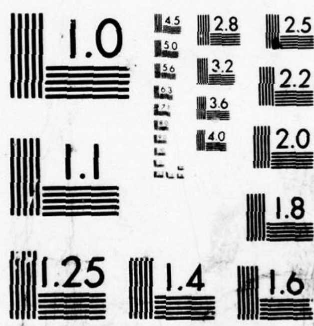

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Report No. FAA-RD-78-158

LEVEL II

12

EVALUATION OF THE PULSED ACOUSTIC DOPPLER WIND SHEAR SENSING SYSTEM AT DULLES INTERNATIONAL AIRPORT

Peter V. Versage
Augusto M. Ferrara

AUGUST 1979

FINAL REPORT

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16. Abstract

This effort was directed toward the test and evaluation of the pulsed acoustic Doppler wind shear sensing system (PADWSS) to determine if the system could accurately and continuously sense windspeed and wind direction at 30-meter (100-foot) intervals from 30 to 510 meters (100 to 1,500 feet) above ground level. Three other wind shear sensing systems were used for comparison: (1) instrumented tethered balloon in close proximity, (2) instrumented aircraft flights using flat runs at various altitudes and glide slope approaches, and (3) radar wind shear sensing. It was concluded that the evaluated PADWSS system cannot be utilized on an operational basis. It was adversely affected by environmental conditions (bare trees, snow) and ground windspeeds in excess of 5 meters/second (9.72 knots).

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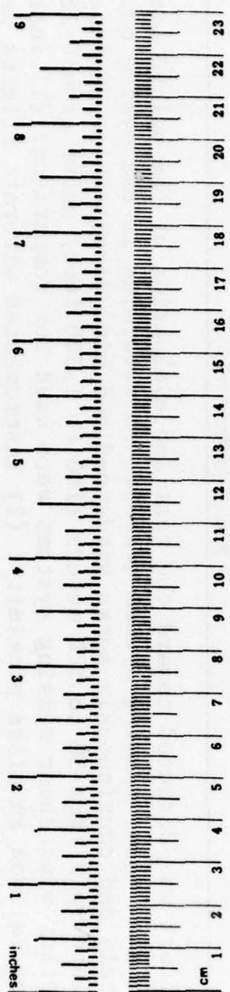
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

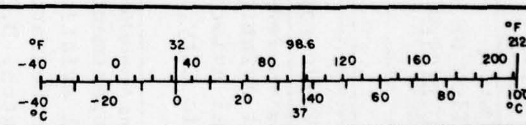
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

PURPOSE.

This effort was directed toward the test and evaluation of the pulsed acoustic Doppler wind shear sensing system (PADWSS) to determine if the system could accurately and continuously sense windspeed and wind direction at 30-meter (100-foot) intervals between a range of 30 and 510 meters (100 and 1,500 feet) above ground level (AGL).

BACKGROUND.

The threat presented by low-level wind shear to aircraft during takeoff and landing operations has been emphasized by a number of wind shear related incidents and accidents that have occurred in the past several years. Aircraft making landing approaches have descended dangerously below their intended glidepath resulting in contact with approach lights, hard short landings, or ground contact short of runway threshold.

The National Transportation Safety Board (NTSB) has established that strong wind shear has been a prime contributory factor in certain aircraft accidents.

The Federal Aviation Administration (FAA) has established several concurrent projects to help provide a solution for the wind shear hazard. One of these projects utilizes a dual-sensor wind shear sensing system consisting mainly of a PADWSS. The PADWSS was developed by the Wave Propagation Lab (WPL) of the National Oceanic Atmospheric Administration under the sponsorship of the FAA. A pulsed Doppler radar wind shear sensing system (PDRWSS) complements the acoustic system when precipitation occurs.

DISCUSSION

SYSTEM DESCRIPTION.

The PADWSS system was installed as part of a dual sensor system at Dulles International Airport. Figure 1 depicts a perspective view of the dual-sensor location with respect to the Dulles terminal and runway areas. The PADWSS was installed approximately 1 mile southwest of the west end of runway 12R/30L and approximately 3 miles west of runway 1L/19R.

Meteorological records at Dulles indicate that weather fronts consistently approach the airport from the west. Since frontal passages are a cause of synoptic-scale wind shears, it was desirable to locate the system at a point where it would detect such shears before they reached the airport approaches. Another important aspect of the site selected was the relatively low background noise level. Analysis of air traffic patterns also indicated that jet aircraft activity in the proximity of the site was light.

The PADWSS was designed to measure wind conditions between heights of 30 to 510 meters (100 to 1,500 feet) AGL providing vertical wind shear data associated with synoptic frontal changes and temperature inversions. The system was not designed to sense low-level horizontal wind shear that is normally associated with gust

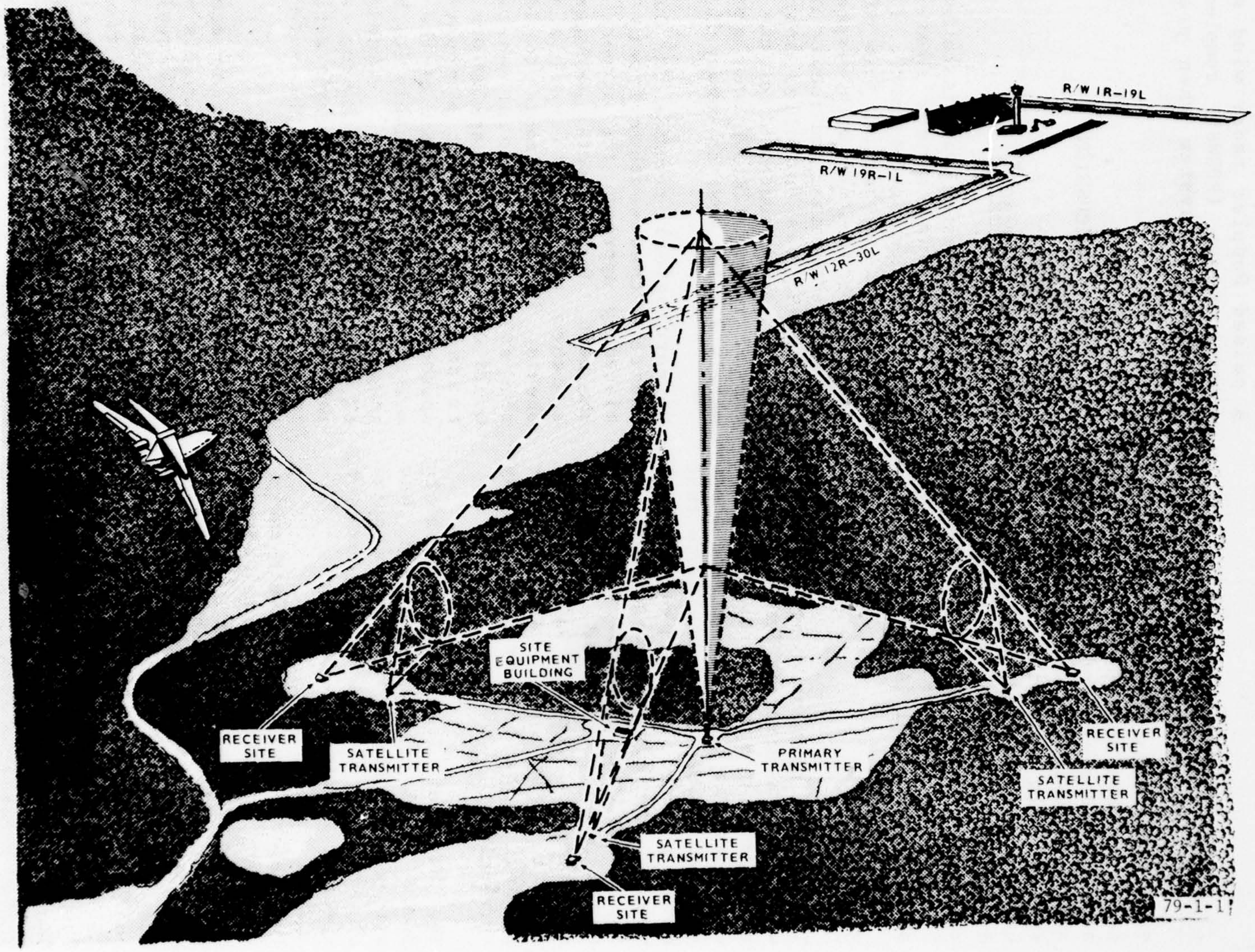

FIGURE 1. SITING CONFIGURATION -- DULLES ACOUSTICAL DOPPLER EQUIPMENT

fronts that precede thunderstorm arrival.

The PADWSS, shown schematically in figure 2, consists of an acoustic transmitter which is an off-axis parabolic horn antenna with a 12-driver array of manifold transducers. The transmitter emits a 1,250-hertz acoustic tone burst directed vertically upward into the atmosphere every 18 seconds. As the upward-traveling pulse passes through the lower atmosphere, a small amount of sound energy is scattered out of the 9° (inverted cone) beam by wind effect. Three parabolic dishes placed in separate bunkers, approximately 300 meters (1,000 feet) from the main transmitter on 120° radii, receive the scattered signal as it passes through the acoustically transparent cover of the bunker. The incoming signal is reflected by the parabolic surface and is collected by receive transducers. The receive antenna is electronically steered to seven positions along vertical axes. The reflected energy from a specific altitude arrives at the receiver after the time required for the sound pulse to traverse the beam, reach altitude, and travel to the receiver. Pulses from the various altitudes are distinguished by the lag time between transmit and receive points. After receipt of signals at the receivers, they are preamplified and conducted by cable to the equipment site building which is adjacent to the transmitter. Further analog processing, such as bandwidth filtering, is followed by digitization and input to a Nova Eclipse Minicomputer.

Smaller satellite transmitters are positioned approximately 50 meters (165 feet) in front of each of the three receiver sites. The smaller satellites pulse simultaneously with each primary pulse. The main transmitter provides measurement from 150 to 510 meters (400 to 1,500 feet) height, and the satellite transmitters provide wind measurements from 30 to 150 meters (100 to 400 feet).

The sound scattered by wind energy imparts a frequency change to the soundwave called a Doppler shift. A digital hardware Fast-Fourier transform is used to extract the Doppler frequency shift. Additional calculations are used to substract noise, determine signal-to-noise ratio, and evaluate the wind profile. This is displayed on a local graphic terminal and archived on magnetic tape. The shifted frequency of the received signal provides a measure of wind velocity and wind direction which is vectorially determined.

Data from two acoustic receivers are required for wind measurement. To determine which receivers are to be used, the noise level of each receiver is measured for each transmitted pulse. Based upon least noise measurements, a pair of receivers is selected by the computer for windspeed calculations.

The PADWSS transmitter pulse repetition rate of 18 seconds is close to the maximum update rate of the system. However, to minimize rapid fluctuations in the measurements (noise), a running average rate which averaged 20 sample measurements (a 6-minute period) was considered optimum. The information so derived was formatted and transmitted for display.

The high sensitivity of the receiver which is necessary for proper operation also represents a limitation

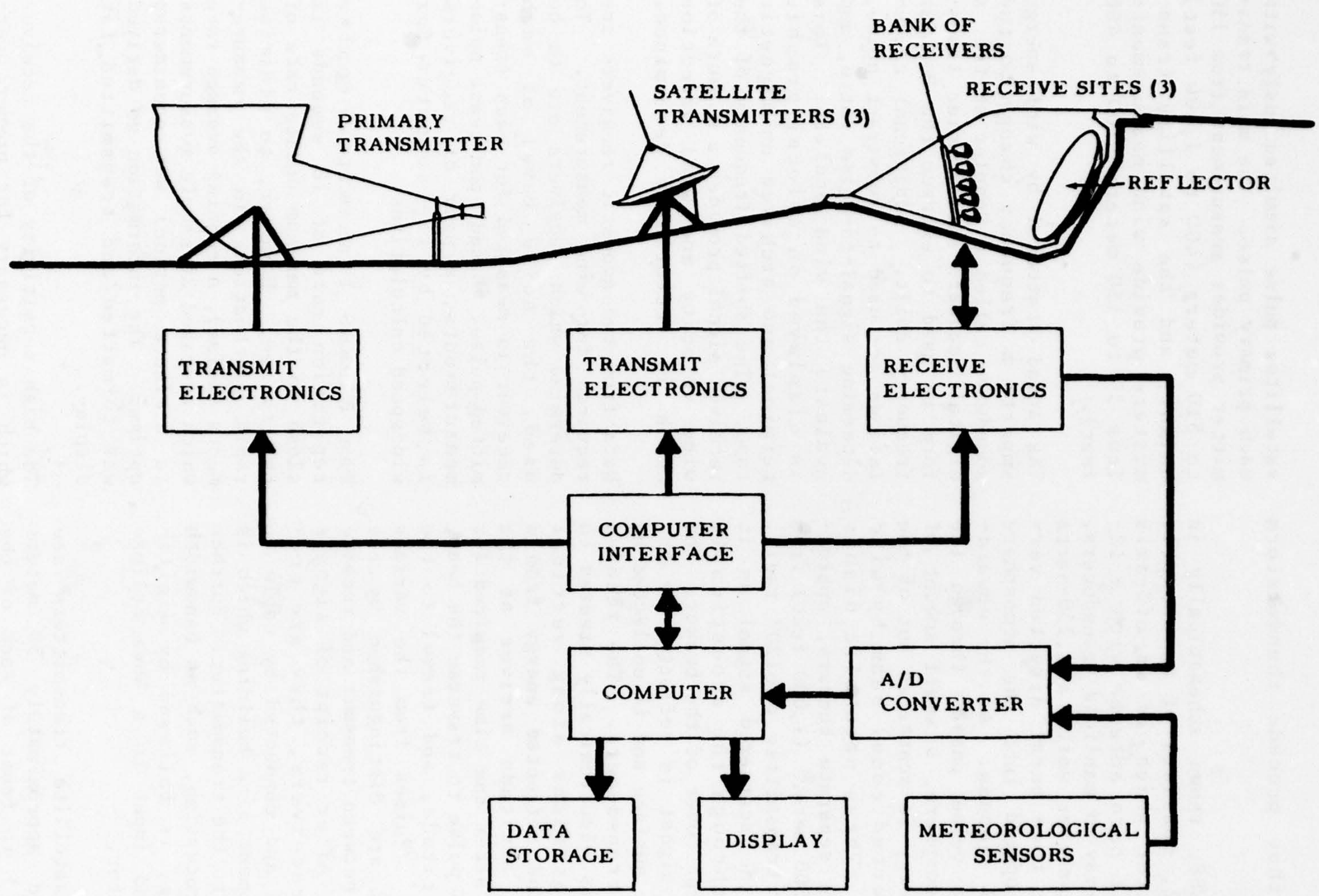

FIGURE 2. BLOCK DIAGRAM--DULLES PULSED ACOUSTICAL DOPPLER WIND SHEAR SENSING SYSTEM

on system capability. High-level ambient noise and overflying by aircraft affect or destroy the required signal-to-noise characteristics. Intermittent noise due to an aircraft passage is handled by rejection filters in the software. In addition, the sound of heavily falling rain also affects or destroys the signal-to-noise characteristics of the acoustic system; therefore, the pulsed Doppler radar is automatically activated during periods of precipitation.

The computer, in addition to determining Doppler frequency shift, controlling pulse repetition rate, beam steering for receivers, and performing data manipulation, is programed to compare the reliability of the acoustic system versus the radar system and to graphically display the most reliable data. When precipitation is no longer present, the radar system shuts down automatically.

TEST OBJECTIVES.

The test activity was planned in two stages. If the results of stage 1 proved acceptable, then stage 2 was to be initiated. The stages are identified as follows:

STAGE 1. Stage 1 involved continuously recording the windspeed and direction measured by the PADWSS and comparing that data for corresponding time periods with data accumulated by the following systems:

1. A National Aviation Facilities Experimental Center (NAFEC) instrumented aircraft,

2. A boundary layer profiler (BLP) which is a tethered, instrumented balloon, and

3. The PDRWSS.

If the results of these data comparisons proved accurate, and if the PADWSS did, in fact, sample wind conditions that truly represented the windspeed and wind direction for the spatial volume of the air terminal, and if an interim assessment of the system's operability and reliability proved acceptable, then stage 2 would be initiated.

STAGE 2. Stage 2 was to design, develop, and evaluate a digital display. The display and associated software were to provide wind shear information when predesignated vectorial differences attributable to windspeed and/or wind directional changes for preselected height ranges were exceeded. An audio alarm and a flashing display were to depict, for the user, the height range in which the most hazardous wind shear condition existed.

It was planned to install the display in the Dulles control tower and have wind shear information relayed to aircrews by ground controllers. However, this second stage was never implemented.

BRIEF DESCRIPTION OF COMPARISON SYSTEMS.

NAFEC-INSTRUMENTED AIRCRAFT. The aircraft (a Grumman Gulfstream) utilizes special transducers, an inertial navigation system (INS), and a true airspeed computer to measure meteorological and navigational parameters. Data were recorded on magnetic tape for 5-second averages.

All aircraft runs were performed under visual flight rules (VFR)

with a minimum windspeed of 5 meters per second (m/s).

Two types of aircraft runs were performed. They are described as follows:

Flat Runs: A flat run was accomplished when the aircraft flew directly into the wind at preselected 100-foot heights above the ground within 300 to 1,500 feet, passing directly over the acoustic system. The aircraft was essentially sampling the same 3- to 7-mile extent (length) of air at a fixed above-ground height that the acoustic system had sampled.

Glide Slope Approaches: Data were collected when the aircraft approached the various runways at Dulles Airport. In this case, the air sampled was a substantial distance from the acoustic system and not necessarily the same air that the acoustic system sampled.

BOUNDARY LAYER PROFILER. The BLP is a kytoon (tethered balloon) with a suspended instrumentation package that senses altitude, windspeed, wind direction, wet bulb temperature, and dry bulb temperature, the values of which are telemetered to a receiver on the ground and recorded on a strip chart recorder. The data were later digitized for comparison with the acoustic data for specific time elements for range of heights between 300 and 1,200 feet AGL.

PULSED DOPPLER RADAR WIND SHEAR SENSING SYSTEM (PDRWSS). The PDRWSS is located immediately adjacent to the PADWSS in the computer building. A precipitation sensor, mounted on the roof, automatically activates the radar when the appropriate moisture content, in the atmosphere, is experienced. The radar provides wind information by measuring the radial velocity of the wind at 100-foot increments, in the height range from 300 to 1,500 feet, in the north, east, south, and west azimuths and combines the sensed measurements into values of windspeed and direction. Data are recorded on magnetic tape along with the data from the PADWSS. The appendix shows a typical listing of both acoustic and radar data. Accompanying this listing are the equations used in the statistical analysis.

ACOUSTIC VERSUS AIRCRAFT.

Table 1 depicts the total number of aircraft runs and data points made to accumulate data for comparison with the PADWSS.

TABLE 1. AIRCRAFT RUNS AND DATA POINTS

Type Run	Number of Runs	Number of Data Points
Flat Runs	22	1,000
Glide Slope Runs	24	950
TOTAL	46	1,950

Note: A data point represents both a windspeed and wind direction.

WINDSPEED. Table 2 depicts the results for statistical computations for windspeed. The mean difference in windspeed for flat runs was -0.67 m/s (1.30 knots) for flat runs with a standard deviation of 2.63 m/s (5.11 knots).

The mean difference in windspeed for glide slope approaches was -0.15 m/s (0.29 knots), a more acceptable value, but with a standard deviation of 2.65 m/s (5.15 knots). The magnitude of these standard deviation values can be attributed to the averaging of aircraft data for 5-second intervals; whereas, the acoustic system is averaged over a 6-minute period. Since averaging the data over a long period of time smooths the effect of turbulence, much of the scatter measured may be attributed to the difference in sampling techniques. To demonstrate this point, the aircraft data from run 14 of September 13, 1977, was averaged over a 2-minute (instead of 5-second) period versus 6 minutes for the acoustic system, and the standard deviation of the windspeed fell to less than 1.1 m/s (2.14 knots).

WIND DIRECTION. Table 3 depicts the results for statistical computations for wind direction. The corrected mean differences reflect compensation for true north used by aircraft instrumentation versus magnetic north used for the acoustic systems.

The mean difference in direction between the acoustic system and the aircraft was -7.2° for the flat runs and -7.4° for glide slope. Much of this difference is a consequence of the acoustic system using true north and the aircraft using magnetic north. If the difference between true and magnetic north is accounted for (6.5°), the mean differences are less than 1°.

The standard deviations of 10.4° for flat runs and 20.9° for glide slope approaches are fairly large and can be attributed to the aircraft data averaging over 5 seconds versus 6 minutes for the acoustic system.

The standard deviation for glide slope runs was approximately twice as large as flat runs (21° versus 10°); however, this can be attributed to

TABLE 2. ACOUSTIC SYSTEM VERSUS AIRCRAFT--WINDSPEED

Type Run	Mean Differences In Windspeed m/s (knots)	Standard Deviations In Windspeed m/s (knots)
Flat Runs	-0.67 (1.30)	2.63 (5.11)
Glide Slope Runs	-0.15 (0.29)	2.65 (5.15)

Note: A negative sign for the mean values indicates that the aircraft-sensed windspeeds, on average, were greater than the acoustic system-sensed windspeeds.

TABLE 3. ACOUSTIC SYSTEM VERSUS AIRCRAFT--WIND DIRECTION

Type Run	Mean Differences In Direction (degrees)	Corrected Mean Difference In Direction (degrees)	Standard Deviation In Direction (degrees)
Flat Runs	-7.2	-0.7	10.4
Glide Slope Runs	-7.4	-0.9	20.9

Note: A negative sign indicates that the aircraft-sensed directions, on the average, were greater than the acoustic system-sensed directions.

crosswinds encountered on glide slope approaches. The error in direction is a function of the difference between the aircraft heading and the wind direction. (Note that flat runs were headed directly into the prevailing wind.)

ACOUSTIC VERSUS BLP.

Table 4 depicts the total hours of comparison time, 26.7, for acoustic versus BLP and the total number of BLP data points. Table 5 depicts the statistical computations for windspeed and wind direction. The results of the BLP comparisons were similar in pattern to the aircraft comparisons; that is, the mean differences were less than 0.1 m/s (0.19 knots) for windspeed and 4.6° for adjusted direction, after compensation for true and magnetic norths. The standard deviations were 1.2 m/s (2.33 knots) for windspeed and 23.3° for direction.

Some of the deviation in direction was probably attributable to the suspended instrumentation package in the BLP being subjected to swaying, oscillation, and flutter (vibration) when the windspeed approaches 10 m/s (19.44 knots). In addition, the BLP data were instantaneous with no averaging versus acoustic system 6-minute averaging.

The BLP was always flown within a 1,000 feet of the acoustic system; therefore, it sensed essentially the same air as the acoustic system.

ACOUSTIC VERSUS RADAR.

Table 6 depicts the approximate number of hours during which the reliability values established by the system developer were high enough to allow a meaningful comparison of the acoustic system (PADWSS) with respect to the radar system (PDRWSS).

When reviewing these acoustic versus PDRWSS data, it became apparent that the data should be categorized for more meaningful evaluation. The breakdowns are given below.

NOVEMBER/DECEMBER 1977 DATA (6-MINUTE AVERAGES). This breakdown was established when it was noted that large standard deviations applied for that time period. Detailed consideration coupled with onsite experience led to the conclusion

TABLE 4. ACOUSTIC SYSTEM VERSUS BOUNDARY LAYER PROFILER

Acoustic Versus BLP Comparison Time (hr)	Number of BLP Data Points
26.7	6,150

Note: A data point represents both windspeed and wind direction.

TABLE 5. ACOUSTIC SYSTEM VERSUS BLP

	Mean Difference	Standard Deviation
Windspeed m/s (knots)	-0.1 (0.19)	1.2 (2.33)
Wind Direction (degrees)	-4.6	23.3

Note: Wind direction is corrected for the difference between true and magnetic north. A minus sign for the mean difference indicates that the BLP values were greater than the acoustic values.

that the absence of leaves on the trees in combination with occasional snow cover adversely affected the acoustic system's signal-to-noise ratio. Without the green foliage which absorbs noise, the reverberations were at a higher level. Snow cover also contributed to this ground clutter by reflecting the transmitted pulses. Another factor that contributes significantly to ambient noise is dry leaf movement in the bunker areas.

A review of the mean differences (table 6) of 1.1 m/s (2.14 knots) in windspeed and 9° in the wind direction provides small concern, but the large standard deviations are cause for concern. Based on 2-sigma statistical computations, one could expect the direction output for the acoustic system to fall anywhere within $\pm 122^\circ$ (standard deviation = 61°) of the mean direction 95 percent of the time and the windspeed to fall within ± 5.6 m/s (± 11.2 knots) (standard deviation = 2.80 m/s (5.44 knots)) of the true windspeed 95 percent of the time for similarly described environmental conditions.

<u>SEPTEMBER THROUGH OCTOBER 1977 DATA (2-MINUTE AVERAGES)</u>. In order to study the system's response to rapidly changing weather conditions (such as thunderstorms), it was decided to lower the averaging time

TABLE 6. ACOUSTIC SYSTEM VERSUS RADAR SYSTEM

Breakdown of Comparison	Hours of Comparison	Mean Difference In Windspeed m/s (knots)	Mean Difference In Direction (degrees)	Standard Deviation In Windspeed m/s (knots)	Standard Deviation In Direction (degrees)
November/ December 1977 (6-minute averages)	55	1.1 (2.14)	9.0	2.8 (5.44)	61.0
September-- Mid-October (2-minute average)	110	0.7 (1.36)	1.6	2.2 (4.28)	29.6
March-- July/Mid-October--Mid-November (6-minute average)	310	1.0 (1.94)	3.5	2.1 (4.08)	33.0
Total Acoustic Versus Radar	475	0.9 (1.76)	6.3	2.2 (4.28)	36.6

Note:

1. Both systems referenced true north.

2. Data for comparison of acoustic versus radar was accumulated under wind conditions more severe than acoustic versus instrumented A/C and acoustic versus BLP. This accounts for the larger differences and standard deviations.

3. Since the quality of the data is not affected by the use of 2-minute averages, it is included as part of the total data set.

from 6 minutes to 2 minutes. The effects of this change were studied during a 6-week period, and it was determined that the averaging change made the system much more sensitive to noise and consequently lowered the profile reliability.

Referring to table 6, it can be noted that the mean differences and standard deviations for the 2- and 6-minute averages are in close agreement; however, the 2-minute averaging time did adversely affect the profile reliability (refer to Profile Reliability section). This implies that the change in averaging time does not affect the quality of the output, but only the quantity of acceptable output.

MARCH THROUGH JULY/MID-OCTOBER THROUGH MID-NOVEMBER (6-MINUTE AVERAGES). The system normally operates on 6-minute averages. Table 6 depicts the mean differences and standard deviations for both windspeed and wind direction for the statistical comparisons. This breakdown presents the most functional data. The system developer (WPL) had indicated that when the averaging time was lowered, the average spectra was increasingly susceptible to perturbation by noise from ground wind and jet aircraft. Our observations confirmed this information. The data in the appendix are part of this category of data.

TOTAL ACOUSTIC VERSUS RADAR. A total of 475 hours of comparative data for the acoustic versus radar was accumulated. This value is the result of computations for the complete data set.

ASSIGNMENT OF SYSTEM ERROR.

Part of NAFEC responsibility in the evaluation process was to appraise the accuracy and repeatability of the acoustic system. There was no established standard to use for comparative purposes; that is, neither the radar, BLP, nor the aircraft could be considered as a standard. Therefore, the rationale for assigning acoustic system values is described under the following headings.

WINDSPEED RATIONALE. The following rationale and computations were utilized.

Acoustic Versus Radar. Since each system was sampling at the same time, an assumption was made that both the acoustic system and the radar system contributed equally to the standard deviation of the differences for that time period when 6-minute averages were being recorded (normal operation). This assumption was based on engineering judgment after detailed observations of the data patterns and the knowledge that the two systems are not sampling the same air. A review of recorded data led to the conclusion that when the moisture content of the environment was adequate, as reflected in the profile reliability of the radar system, the radar system was insensitive to changes in the level of magnitude of windspeed; therefore, the radar system accuracy was consistent. Referring to table 7, the standard deviation for comparison of acoustic versus radar was 2.1 m/s (4.08 knots). It was determined that an equal assignment of 1.5 m/s (2.92 knots) be allocated to both the acoustic and radar systems for 6-minute average data.

TABLE 7. CALCULATED STANDARD DEVIATIONS FOR WINDSPEED--METERS/SECOND (KNOTS)

Type of Comparison	Standard Deviation of Comparison	Calculated Standard Deviation: Acoustic System	Radar System	Instrumented Aircraft	BLP
March--July/ Mid-October--Mid-November Radar versus acoustic (6-minute average)	2.1 (4.08)	1.5 (2.92)	1.5 (2.92)	NA	NA
September--Mid-October Radar versus acoustic (2-minute average)	2.2 (4.28)	1.6 (3.11)	1.5 (2.92)	NA	NA
November/December 1977 Radar versus acoustic (6-minute averages)	2.8 (5.44)	2.4 (4.67)	1.5 (2.92)	NA	NA
Total radar versus acoustic	2.2 (4.28)	1.6 (3.11)	1.5 (2.92)	NA	NA
Aircraft versus acoustic flat runs	2.6 (5.05)	1.6 (3.11)	NA	2.0 (3.89)	NA
Aircraft versus acoustic glide slopes	2.6 (5.05)	1.6 (3.11)	NA	2.0 (3.89)	NA
BLP versus acoustic	1.2 (2.33)	0.85 (1.65)	NA	NA	0.85 (1.65)

Note: Refer to the text under windspeed rationale for a description of the assumptions made to compute this table. NA means not applicable for this type comparison.

Using a constant assignment of 1.5 m/s (2.92 knots) for the system resulted in the following calculated standard deviation values for the acoustic system. They were:

1. September--Mid-October = 1.6 m/s (3.11 knots) (2-Minute Averages)

2. November/December 1977 = 2.4 m/s (4.67 knots) (6-Minute Averages)

3. Total = 1.6 m/s (3.11 knots)

Acoustic Versus Aircraft Instrumentation. The calculated standard deviation for windspeed for 6-minute averages for the acoustic system was subsequently used in the formula to determine the standard deviation for windspeed attributable to the aircraft's instrument system; this resulted in a standard deviation of 2 m/s (3.89 knots) for the aircraft (table 7). Some of the difference can be attributed to the short averaging time for the aircraft data.

Acoustic Versus BLP. The maximum allowable windspeed for BLP use was 10 m/s (19.44 knots). This resulted in a comparatively low standard deviation for BLP versus acoustic of 1.2 m/s (2.33 knots) (table 7). For this comparison, it was assumed the acoustic and BLP system equally contributed to half of the deviation; therefore, the respective deviations were 0.85 m/s (1.65 knots). The reduced deviation at low windspeed implies that as windspeed increases, so does the uncertainty associated with the acoustic systems measurement of windspeed.

Summary for Windspeed Rationale. In summary, for windspeed rationale, the engineering requirement identifies an accuracy of ±5 knots (2.57 m/s). This requirement was interpreted as being two standard deviations, which means that any system which met this requirement would output data that would be within ±5 knots 95 percent of the time. This converts to one standard deviation of 1.3 m/s (2.53 knots).

Per the data from table 7, the following is condensed:

Type of Comparison	Calculated 1 Std. Dev. m/s (knots)	Engineering Requirement 1 Std. Dev. m/s (knots)
March--July/Mid-October--Mid-November Acoustic (compared with radar, 6-minute average)	1.5 (2.92)	1.3 (2.53)
September--Mid-October Acoustic (compared with radar, 2-minute average)	1.6 (3.11)	1.3 (2.53)
November/December 1977 Acoustic (compared with radar, 6-minute average)	2.4 (4.67)	1.3 (2.53)
Acoustic (compared with aircraft)	1.6 (3.11)	1.3 (2.53)
Acoustic (compared with BLP)	0.85 (1.65)	1.3 (2.53)

WIND DIRECTION RATIONALE. Similar rationale and computations were utilized in determining the standard deviations for the wind direction as used in the windspeed rationale.

Acoustic Versus Radar. It was assumed that the acoustic system and the radar system equally contributed to the comparative standard deviation of 33° for March--July/Mid-October--Mid-November, 6-minute average data (refer to table 8). Applying a formula for distribution of assigned contribution of error resulted in a standard deviation value of 23.3° for both the acoustic and radar systems.

Reference should be made to table 8, which depicts March--July/Mid-October--Mid-November (6-minute averages); and November/December (6-minute averages) wind direction values. Particular attention should be given to the standard deviation established for the November/December 1977 time period when the acoustic system was adversely affected by environmental conditions (bare trees and snow cover). The acoustic system's standard deviation for that time period indicates a potential of error equivalent to approximately 113° (2-standard deviations), strong evidence that the system fails to function accurately in all environments.

Acoustic Versus Aircraft Instrumentation. Allowing for atmospheric conditions and other factors, the standard deviation for the acoustic system was 10° (refer to table 8). Utilizing these same allowances for aircraft flat runs resulted in a standard deviation of 3.0° for the aircraft, a reasonable value for aircraft heading directly into the wind, where errors in measuring direction are minimized.

For the glide slope approaches, assigning the same 10° standard deviation to the acoustic system, the aircraft was subjected to crosswind influence, and a standard deviation of 18.4° resulted.

Acoustic Versus BLP. Based on the standard deviation of 10° assigned to the acoustic system when compared to the aircraft and the similarity in atmospheric conditions for flight days for aircraft and BLP, it was decided to assign a standard deviation of 10° to the acoustic system for BLP comparisons. By a deductive computation, this resulted in the assignment of 21° of standard deviation to the BLP from the comparative standard deviation of 23.3°. This assignment of 21° appears reasonable when one considers the swaying, oscillations, and flutter that the BLP experiences under varying wind conditions (refer to table 8).

Summary For Wind Direction Rationale. Meaningful comparisons are summarized for wind direction rationale. The engineering requirement identified an accuracy of $\pm 20°$ which equates to 1 standard deviation of 10°.

TABLE 8. CALCULATED STANDARD DEVIATIONS FOR WIND DIRECTION--DEGREES

Type of Comparison	Standard Deviation of Comparison	Calculated Standard Deviation			
		Acoustic System	Radar System	Instrumented Aircraft	BLP
March--July/ Mid-October--Mid-November Radar versus acoustic (6-minute average)	33.0	23.3	23.3	NA	NA
September--Mid-October Radar versus acoustic (2-minute average)	29.6	18.3	23.3	NA	NA
November/December 1977 Radar versus acoustic (6-minute averages)	61.0	56.4	23.3	NA	NA
Overall radar versus acoustic	36.6	28.2	23.3	NA	NA
Acoustic versus aircraft flat runs	10.4	10.0	NA	3.0	NA
Acoustic versus aircraft glide slopes	20.9	10.0	NA	18.4	NA
Acoustic versus BLP	23.3	10.0	NA	NA	21.0

Note: NA means not applicable for this type of comparison. The values tabulated above were computed using the assumptions described in the text under Wind Direction Rationale.

The results are unfavorable for acoustic when compared to radar, particularly for the November/December 1977 described conditions. This degree of variation would have an adverse effect on display operation. Algorithms were to be developed that would allow the computer to sense vector differences attributable to change in wind direction and/or wind velocity for values as low as 10 knots between preselected height ranges above ground level. The large angular deviations may have caused false alarms for air traffic controllers if stage 2 had been implemented or possibly allowed a hazardous condition to develop without sensing it because of the exceedingly large element of error.

Per table 8, the following is condensed for standard deviations:

PROFILE RELIABILITY ANALYSIS.

As previously indicated, a program was developed to determine the percentage of time when the acoustic systems profile reliability was equal to or exceeded a discrete value of 30, as identified by the system developer. The results of this analysis are tabulated in table 9. A review of the table will indicate that when March--July/Mid-October-Mid-November 6-minute averaging was used (normal operating average), data were available 92 percent of the time. This figure diminished to 85 percent when September--Mid-October 2-minute averages were used and further diminished to 72 percent during the conditions previously described for the November/December 6-minute averages.

A program was used to measure the profile reliability of the acoustic

Type of Comparison	Calculated 1 Std. Dev. (degrees)	Engineering Requirement 1 Std. Dev. (degrees)
Acoustic compared with radar March--July/Mid-October--Mid-November (6-minute average)	23.3	10.0
Acoustic (compared with radar) November/December (6-minute averages)	56.4	10.0
Acoustic (compared with aircraft, glide slopes)	10.0	10.0
Acoustic (compared with BLP)	10.0	10.0

TABLE 9. PROFILE RELIABILITY ANALYSIS

Condition Influencing Acoustic Operation	Number of Data Points	Number of Points With Good Reliability	Percent Data Available
<u>Ambient Conditions</u>			
November/December 1977 6-Minute Averages of Acoustic Data	94,486	67,930	71.9
September--Mid-October 2-Minute Averages of Acoustic Data	189,098	160,833	85.1
March--July/Mid-October--Mid-November 6-Minute Averages of Acoustic Data	469,620	429,910	91.5
Overall Acoustic Operation	753,204	658,673	87.4

Note: Time elements for each breakdown for this analysis were as identified in table 6.

TABLE 10. PROFILE RELIABILITY ANALYSIS WITH GROUND WINDSPEED IN EXCESS OF 5 METERS/SECOND

Condition Influencing Acoustic Operation	Number of Data Points	Number of Points With Good Reliability	Percent Data Available
<u>Ambient Conditions</u>			
November/December 6-Minute Averages of Acoustic Data	7,830	4,367	55.8
September--Mid-October 2-Minute Averages of Acoustic Data	10,980	8,298	75.6
March--July/Mid-October--Mid-November 6-Minute Averages of Acoustic Data	28,658	22,933	80.0
Overall Acoustic Operation	47,466	33,598	75.0

Note: Time elements for each breakdown for this analysis were as identified in table 6.

system whenever the ground windspeed exceeded 5 m/s (9.72 knots). Table 10 shows that the profile reliability diminished substantially for all categories. For March--July/Mid-October--Mid-November 6-minute averaging, the reliability changed from 91.5 to 80.0. For 2-minute averages, the reliability changed from 85.1 to 75.6. For the November/December 1977 period, it changed from 71.9 to 55.8.

When the ground windspeed exceeded 10 m/s (19.44 knots), the programed analysis indicated that the profile reliability almost invariably failed to exceed the established minimum value of 30, which for practical applications made the data useless. Onsite observations of the profile as displayed on a cathode-ray tube (CRT) substantiated this condition. The data analysis indicated that this condition existed for approximately 2 out of 5,933 hours of total uptime.

Additional evaluation indicated that the higher AGL height measurements failed to meet the minimum profile reliability test regularly when the winds at the 30-meter (100-foot) level exceeded 8 m/s (15.5 knots). When the winds at that same level exceeded 11 m/s (21.38 knots), the wind profiles were discontinuous, and the wind information for every 30-meter (100-foot) height was not sensed. These conditions were also evidenced through onsite observation of the CRT display.

In summary, this analysis and observations further substantiate the unsuitability of the system for air traffic controller use.

DOWNTIME ANALYSIS.

Table 11 has been assembled on the basis of information extracted from a daily log. One column identifies the cause of downtime by event, and in some cases, the events are further defined with subevents. An adjunct column identified the hours attributable to events and subevents, where applicable, and the remaining column identifies the downtime percentage of total hours. Most of the events and subevents are self-explanatory; however, some of them require amplification or clarification.

ITEM 4 - HARDWARE PROBLEM, FFT. This item was a Fast-Fourier transform (FFT) board. The item was returned to the contractor in California for two independent failures. No spare board was provided. Each time that the FFT failed, it had to be recycled at least twice per failure to and from the contractor for correction. Obviously, the final assembly test the manufacturer had developed was not adequate. Almost 2,800 hours can be attributed to this failure alone.

ITEM 5 - "QUICK" LOOK. This routine, used for extracting a recorded information from magnetic tapes onsite, preempted computer data collection.

ITEM 7 - SOFTWARE CHANGES. This item occurred as a result of modifications incorporated per the recommendation of the system developer.

DOWNTIME COMMENTS AND CALCULATIONS. Both items 5 and 7 would not occur

TABLE 11. DOWNTIME SUMMARY

TOTAL HOURS OF OPERATION: 10,176 (2/15/77 TO 4/15/78)

Item	Cause of Downtime	Downtime		% of Total	
1	Tape Changes:				
	Normal	33.5		0.3	
	Aircraft Runs	9.5	43.0	0.1	0.4
2	System Maintenance:				
	Replace Parts	37.0		0.4	
	Pointing Angles	14.0		0.1	
	Electronic Checks	10.5	61.5	0.1	0.6
3	Computer Maintenance:				
	Repairman on Site	40.0		0.4	
	Wait for Parts	215.0	255.0	2.1	2.5
4	Hardware Problem--FFT:				
	Wait for Data General	116.0		1.4	
	D. G. Repairman on Site	106.5		1.0	
	NAFEC/WPL Working on FFT	92.5		0.9	
	Wait for Parts D. G.	240.0		2.4	
	Wait for FFT	2,688.0		26.4	
	Online/No Tape	110.0	3,353.0	1.1	33.0
5	"Quick" Look	34.2	34.2	0.3	0.3
6	Install CRT at National Weather Service	13.5	13.5	0.1	0.1
7	Software Changes	39.0	39.0	0.4	0.4
8	Power Outages:				
	Lightning	88.8		0.9	
	Other--Wind and Ice	76.0	164.8	0.7	1.6
9	Miscellaneous Computer Crashes	60.4	60.4	0.7	0.7
10	Miscellaneous	218.7	218.7	2.1	2.1
	TOTAL DOWNTIME		4,243.1		41.7

under pure operational conditions. Item 8 was curtailed and effectively reduced when an uninterruptible power supply was installed in November 1977 which provided backup battery power for 1/2 hour when utility power was interrupted. This reduced the frequent computer crashes that occurred because of momentary power interruptions.

If adequate spares are provisioned and most of the unneeded events are eliminated, the downtime could substantially be reduced to approximately 727 hours in 10,000 hours or 7.25 percent of total operating time. This estimate is based on limited onsite experience and makes no allowance for system degradation.

A mean time between failures (MTBF) of 178 hours and a mean time to repair (MTTR) of 115 hours were calculated from daily (hourly) logs maintained onsite. MTBF equates to about one failure every 7 1/2 days and MTTR equates to about 5 days to repair the system once a failure occurred.

These values can be reduced by provisioning a spare FFT board. If one had been available, the repair could have been implemented in approximately 20 hours. If, in addition, an uninterruptable power supply had been installed prior to the start of evaluation, the MTBF would have been approximately 250 hours. Major redesign would be required to improve upon these values.

A major portion of the failure associated with items 3, 4, and 8 could be attributed to storm activity or power interruptions or failure.

CONCLUSIONS

From the results, it was concluded that:

1. The evaluated PADWSS system cannot be utilized on an operational basis to provide accurate, timely, wind shear information to potentially affected aircrews.

2. The acoustic system failed, by a wide margin, to meet the standard deviation (repeatability) values for direction, calculated per the engineering requirements. (The engineering requirement (FAA ER-450-130B) identified a repeatability of ± 5 knots and $\pm 20^{\circ}$ which transcribes to an acceptable 2 standard deviation of 2.53 m/s and 10° for all weather conditions.)

3. The system validity is affected by environmental conditions and ground windspeeds. When trees were bare, snow covered the ground, and ground windspeeds exceeded 5 m/s (9.72 knots), valid data output dropped to 56 percent of the time.

4. When the ground windspeed exceeded 10 m/s (19.44 knots), no data output was available from the PADWSS.

5. When the windspeed at the 30-meter (100-foot) level exceeded 8 m/s (15.55 knots), the upper AGL height measurements would fail to meet the established profile reliability criteria.

6. These aforementioned environmental conditions could occur at times when hazardous wind shear conditions exist.

RECOMMENDATION

It is recommended that the PADWSS not be utilized on an operational basis.

APPENDIX A

STATISTICAL ANALYSIS AND SAMPLE DATA

A statistical approach was used to handle the volume of data that was generated. These calculations are summarized below. The first step in the analysis is to find the difference between the two systems. This is defined as:

$$d_i = d_a - d_o$$

where: d_i = the difference for this data point

d_a = the windspeed (or wind direction) from the acoustic system

d_o = the corresponding variable from the system with which the comparison is being made

Next, the arithmetic mean or average difference is computed by summing all the individual differences and dividing by the number of data points.

$$D = \frac{d_1 + d_2 + d_3 + \ldots + d_n}{n}$$

where: D = the arithematic mean

d_1, d_2, etc. = are the individual differences

n = the number of data points involved

Finally the formula used for the standard deviation is:

$$s^2 = \frac{\sum d_i^2 - \frac{(\Sigma d_i)^2}{n}}{n-1}$$

where: S = the standard deviation of the difference

Σ = the sum from point one through point n.

If one assumes that the errors induced in each system are independant of one another, the standard deviation of each system is related to the standard deviation of the difference by the following equation:

$$S^2 = S_a^2 - S_o^2$$

where S_a = the standard deviation of the acoustic system

S_o = the standard deviation of the system which is compared to the acoustic system

Since S is calculated from the data collected, this equation is useful for estimating the variability of the systems used in this evaluation.

EXPLANATION OF DATA TABULATIONS.

Listed on the following pages is a sample of the data from the PADWSS versus radar comparisons for October 27, 1977. This data was collected using 6-minute averages and was included as part of the normal operation data. In the columns from left to right are listed the date that data were collected, the time, the PADWSS reliability, the PADWSS windspeed and direction, the radar reliability, the radar windspeed and direction, the height at which the data were collected in meters, the difference in speed and the difference in direction.

At the end of the listing is *printed* the statistical summary. In this case, the mean difference in windspeed is 0.98 m/s (1.90 knots); the mean difference in direction is 7.74°; the standard deviation of the difference in windspeed is 1.21 m/s (2.35 knots); and the standard deviation of the differences in direction is 17.16°.

TABLE A-1. TYPICAL COMPUTER DATA SHEET

SNUMB = 7616T, ACTIVITY # = 03, , REPORT CODE = 06, RECORD COUNT = 002425

DATE	TIME	ACOUSTIC REL.	ACOUSTIC SPD	ACOUSTIC DIR	RADAR REL.	RADAR SPD	RADAR DIR	HEIGHT GATE	DIFFERENCE IN SPEED	DIFFERENCE IN DIR
10 27 77	11 55 49	33.3	0.	0.	50.0	5.9	36.1	150.	-5.9	-36.1
10 27 77	11 56 42	45.4	6.7	42.8	100.0	4.4	31.9	150.	2.4	10.9
10 27 77	11 57 1	48.1	6.6	43.3	90.0	4.4	31.9	150.	2.2	11.4
10 27 77	11 57 18	50.6	6.5	43.9	100.0	5.0	43.4	150.	1.6	0.5
10 27 77	11 57 18	50.6	5.6	50.4	100.0	5.2	49.6	180.	0.4	0.8
10 27 77	11 57 37	53.0	6.6	43.2	90.0	5.0	43.4	150.	1.6	-0.2
10 27 77	11 57 37	53.0	5.7	50.3	90.0	5.2	49.6	180.	0.5	0.6
10 27 77	11 57 54	55.3	6.7	41.8	81.0	5.0	43.4	150.	1.7	-1.6
10 27 77	11 57 54	55.3	5.8	50.0	81.0	5.2	49.6	180.	0.6	0.3
10 27 77	11 58 13	57.5	6.7	41.9	100.0	5.0	41.7	150.	1.7	0.1
10 27 77	11 58 13	57.5	5.8	51.1	50.0	5.6	56.6	180.	0.2	-5.5
10 27 77	11 58 13	55.2	7.2	51.4	75.0	5.6	38.5	210.	1.6	12.9
10 27 77	11 58 31	59.6	6.9	39.7	90.0	5.0	41.7	150.	1.9	-2.0
10 27 77	11 58 31	57.4	7.1	50.7	67.5	5.6	38.5	210.	1.5	12.2
10 27 77	11 58 50	61.6	7.3	39.1	100.0	4.8	38.3	150.	2.4	0.8
10 27 77	11 58 50	59.5	7.1	51.2	50.0	5.4	45.7	210.	1.7	5.4
10 27 77	11 59 7	63.5	7.2	39.0	90.0	4.8	38.3	150.	2.4	0.7
10 27 77	11 59 25	65.3	7.4	37.9	75.0	5.0	36.9	150.	2.4	1.0
10 27 77	11 59 25	65.3	6.0	48.3	50.0	5.4	44.3	180.	0.6	4.0
10 27 77	11 59 43	67.0	7.3	37.4	67.5	5.0	36.9	150.	2.3	0.5
10 27 77	12 0 1	68.6	7.1	39.2	60.7	5.0	36.9	150.	2.1	2.3
10 27 77	12 0 19	70.1	7.0	40.6	100.0	5.0	39.4	150.	1.9	1.2
10 27 77	12 0 19	61.0	6.2	47.9	50.0	5.7	45.7	180.	0.4	2.2
10 27 77	12 0 19	68.5	7.0	48.9	50.0	5.0	55.7	210.	2.1	-6.8
10 27 77	12 0 37	66.6	7.0	40.3	90.0	5.0	39.4	150.	1.9	0.9
10 27 77	12 0 54	65.7	7.0	40.9	75.0	5.3	28.0	150.	1.6	12.9
10 27 77	12 0 54	56.6	6.2	47.9	75.0	6.2	42.4	180.	-0.1	5.5
10 27 77	12 0 54	59.4	7.0	57.9	50.0	6.6	46.2	270.	0.4	11.6
10 27 77	12 0 54	54.9	7.7	54.1	50.0	6.8	51.6	300.	1.0	2.5
10 27 77	12 1 13	67.4	7.0	41.4	67.5	5.3	28.0	150.	1.6	13.4
10 27 77	12 1 13	58.7	6.2	48.3	67.5	6.2	42.4	180.	-0.1	5.9
10 27 77	12 1 31	68.9	7.0	41.4	60.7	5.3	28.0	150.	1.6	13.4
10 27 77	12 1 31	60.7	6.2	47.1	60.7	6.2	42.4	180.	-0.1	4.7
10 27 77	12 1 49	70.5	7.1	41.3	100.0	5.2	31.0	150.	1.8	10.3
10 27 77	12 1 49	62.6	6.2	47.8	75.0	4.3	59.3	180.	1.9	-11.4
10 27 77	12 1 49	68.5	7.2	44.9	50.0	5.6	47.2	210.	1.6	-2.3
10 27 77	12 2 7	71.9	7.1	41.3	90.0	5.2	31.0	150.	1.8	10.3
10 27 77	12 2 7	64.5	6.2	46.9	67.5	4.3	59.3	180.	1.9	-12.3
10 27 77	12 2 26	73.3	7.0	41.1	50.0	6.5	31.7	150.	0.5	9.4
10 27 77	12 2 26	71.5	7.1	45.1	50.0	7.5	48.2	210.	-0.4	-3.1
10 27 77	12 3 1	75.8	7.1	40.8	75.0	4.3	29.6	150.	2.8	11.2
10 27 77	12 3 1	69.4	6.1	49.2	50.0	6.3	36.0	180.	-0.2	13.2
10 27 77	12 3 19	74.4	7.0	42.2	67.5	4.3	29.6	150.	2.8	12.6
10 27 77	12 3 38	75.7	7.1	41.3	60.7	4.3	29.6	150.	2.8	11.7
10 27 77	12 3 55	76.8	7.2	40.9	75.0	4.0	45.0	150.	3.3	-4.1

TABLE A-1. TYPICAL COMPUTER DATA SHEET (CONT'D)

SNUMB = 7616T, ACTIVITY # = 03, , REPORT CODE = 06, RECORD COUNT = 002425

DATE	TIME	ACOUSTIC REL.	ACOUSTIC SPD	ACOUSTIC DIR	RADAR REL.	RADAR SPD	RADAR DIR	HEIGHT GATE	DIFFERENCE IN SPEED	DIFFERENCE IN DIR
10 27 77	12 4 13	78.0	7.3	42.1	67.5	4.0	45.0	150.	3.3	-2.9
10 27 77	12 4 31	79.0	6.9	41.9	75.0	4.8	38.3	150.	2.0	3.6
10 27 77	12 4 51	77.5	6.9	41.6	67.5	4.8	38.3	150.	2.0	3.3
10 27 77	12 5 7	76.1	6.9	40.2	60.7	4.8	38.3	150.	2.1	1.9
10 27 77	12 5 25	77.2	6.4	46.4	100.0	5.4	36.7	150.	1.0	9.8
10 27 77	12 5 43	64.4	5.9	52.2	90.0	5.4	36.7	150.	0.6	15.5
10 27 77	12 6 2	66.1	5.7	51.2	75.0	3.5	36.9	150.	2.2	14.3
10 27 77	12 6 19	66.1	5.7	49.6	67.5	3.5	36.9	150.	2.2	12.7
10 27 77	12 6 38	66.1	5.8	48.3	100.0	4.3	29.6	150.	1.5	18.7
10 27 77	12 6 38	82.0	6.5	45.8	50.0	5.5	29.4	180.	1.0	16.5
10 27 77	12 6 55	67.7	5.7	49.9	90.0	4.3	29.6	150.	1.4	20.3

TABLE A-2. TYPICAL COMPUTER SUMMARY DATA SHEET

POINTS	SUM OF SQUARES		SUM OF DELTAS		AVERAGE DELTAS		VARIANCES		STANDARD DEVIATION		
2239.00	5405.85	792738.12	2184.99	17327.57	0.98	7.74	1.46	294.30	1.21	17.16	
2239	2239	2239	2224	2214	2141	1962	1532	685	0		
2239	2239	2239	2239	2239	2036	1656	1386	1154	578		